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1 Embodied pain—negotiating the boundaries of possible action

2

3 Abby Tabor\*, Edmund Keogh, Christopher Eccleston

4 Centre for Pain Research, University of Bath, UK.

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6

7 \* Corresponding author

8 Abby Tabor, PhD

9 Centre for Pain Research

10 Department for Health (1 West)

11 University of Bath

12 BA2 7AY, UK

13 +441225 384225

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## 1. Introduction.

Pain is a protective strategy, which emerges from on-going interaction between body and world. Pain is, however, often thought of as a unitary output—an end product experienced as an intrusion upon an often unsuspecting perceiver [56]. We know a lot about how nociception relates to pain, informed by both biological and psychological influences [30,70,98], about how pain intrudes into awareness [5,26,29,34], and how it relates to clinical variables such as suffering and disability [35]. However, despite significant advances, the mechanisms of pain intrusion remain elusive [63]. In this paper we stress a functional view of pain as more than experience; as defensive action operating in the context of uncertain threat.

Although traditional characterisations of perception as a product of sensory information have been critiqued [19,41,53], including in pain [89,96], there is now a well advanced contemporary view that all perception is embodied and embedded [41,67,79,88]. Here, **embodied** is defined by action, the premise that cognition extends beyond the brain so that an ever-changing body is at the core of how our experiences are shaped; this may be the unconscious workings of our immune system or the collaborative efforts made to avoid movement. **Embedded** refers to the situated interaction between the embodied being and the external environment, in both place (current context) and time (evolutionary context).

From this view, all experience is inferential [78], dynamic [22,55], and related to action in the world [2,21,24]. Thus, to describe the experience of pain we must understand it within its evolved, learned, and ultimately threat-defined context [33,101]. Theories of embodied experience are well advanced elsewhere, most notably in cybernetics [4,23,81], evolutionary biology [39,75,82] and consciousness [83,84]. Its provenance can be traced to structural psychology [93], phenomenology [47,53,62], and perception

[41,77]. However, embodied domains have avoided pain, considering it either too simple [32] or paradoxically too difficult [6].

Our embodied view, in many ways complements existing literature [18,27,36,42,97] supporting the growing understanding of pain as an experience inferred from uncertain information [3,17,85,100]. However, it critically looks to extend this work beyond a passive, information processing model that has come to dominate [49]. Here, we emphasise the body, not separate from the brain nor the world, but part of the facility that actively shapes our experience of pain. This perspective defines pain in terms of action: an experience which, as part of a protective strategy, attempts to defend one's *self* in the presence of inferred threat.

We start with a consideration of the core features of embodied pain. Next, we review the few studies that have been attempted on embodied perception and pain. Finally, we discuss how this approach can be applied usefully to pain, exploring both the research and clinical implications of embodied pain.

## 2. Inferring experience in an uncertain world

In proposing a view of pain as embodied and embedded, we draw upon three principles from the broader literature on embodied experience: inference, liminality, and defence. First, all experience is inferred, and inference functions principally to maintain coherence in complex and inherently uncertain environments—*inference*. Second, all experience is fundamentally defined by the boundaries of possible action—*liminality*. Third, all experience can be disturbed by bodily threat: pain is an action that functions to reduce threat; promoting defence and maintaining the integrity of coherent behaviour—*defence*.

### 2.1. Inference

We know now that our experiences are inferred [47, 89]: we fill in the gaps [44], selectively attend [1,31], unconsciously prime [10,50], and in essence prioritise efficiency over accuracy [52,94]. Perception results from attempts to accommodate information that has deviated from our predictions [20]. It is only through the actions of our body and our predictions of the consequences of these actions that we are able to disambiguate the world [39]. Thus, the reciprocal relationship between action and prediction continually reshapes our experience of pain.

Perception as inference can be characterised computationally [103], and has been explored in pain [3,17,61]. Critically, however, the role of the body is often relegated in these more reductionist models, overshadowed by the dominant view of pain as a phenomenon of the brain [99]. In contrast, experience from an embodied perspective is borne out of the hierarchical, sensorimotor interactions we have with the world [40,73,74]. Importantly, this accounts for the changing ability of the individual to act in their environment, as well as what the environment affords. When pain is included within this sensorimotor interaction, it can be considered an action that deliberately alters the way in which we are able to interact with our environment and so in turn, changes what the environment affords.

## *2.2. Liminality*

Experience can be thought of as a strategy generated from the need to continually adjust our actions when our predictions emerge as inadequate, i.e., a mismatch that does not provide a coherent basis for action [23,51]. The need for homeostatic coherence above all else drives experience [9,25,81]. Pain, along with other bodily experiences (e.g. fatigue, itch, temperature, pressure and disequilibrium) that intrude upon awareness indicate that boundaries have been reached and action must be taken—they are liminal experiences.

### 2.3 Defence

Much of the active inference we describe occurs outside of awareness. Like a stream following a well-worn channel defined by natural banks that guide and constrain, so felt experience flows largely uninterrupted, embodied by physical constraints and embedded within social constraints. To stray outside of these bounds produces specific alerts that function to modify our actions or alter our predictions. Each physical sense has a specific threat tied to specific defensive actions, which attempt to return the individual to within viable constraints [28].

In some circumstances those defensive actions are insufficient and the result is experienced as disturbing, e.g., *das unheimliche* phenomena in which we experience incoherent perceptions of familiarity; an illusion of relationship, in which objects are uncannily personal [38]. When all defensive actions fail there emerge whole system delusional experiences, including repression, de-realization, and—as the final defence—dissociation [12,13,58].

### 3. Embodied pain motivating action

First we review research on how pain influences non-pain perceptual judgement, and the obverse- *inference*. Second, we consider studies of action constrained when it meets the boundaries imposed by the body in pain, studied as illusions that alter the experience of pain- *liminal*. Third, we consider examples of whole body disturbances for their accounting of pain, studied as specific experiences of pain related dissociation, or global experiences of delusion, in a final defence by departure- *defence*.

There is a small body of experimental work on how the experience of pain can alter non-pain perception. For example, we have shown that pain affects judgements of distance when the object-distance being judged is threat-related [91], an observation

134 previously made in patients with clinical pain [102]. Similarly, pain can affect  
135 judgements of the weight of external objects [90], and the weight, size, and shape of  
136 one's own body [67,69]. Clinically, reports of pain, temperature, stiffness, and  
137 imbalance are hard to disentangle, so often appear together [68], and have yet to be  
138 experimentally separated. Without such finesse, attempts to capture embodied  
139 experience rightly faces scrutiny and challenge [37]; although studies have replicated  
140 the effects of higher order cognition and mood on pain [11,92]. There are also studies  
141 of counter-stimulation offered in competition to pain as distraction [59]. Evidence from  
142 direct experimental studies conducted shows pain to be dynamic, flexible, and  
143 connected; a reflection of inference in an uncertain world.

144  
145 Illusory experience goes beyond altered sensory judgements. 'Illusory' is  
146 normally judged as impossible or improbable perception based on a common  
147 agreement on the world; for example, if I perceive a limb that every external observer  
148 knows me to have lost. Painful missing body parts are a common experience for  
149 amputees [72], although they are rarely reported in isolation from temperature,  
150 pressure, weight, size and itch phenomena. Visual counter-stimulation using mirrors  
151 or virtual reality can alter aspects of size, position, and ownership, but also pain  
152 [15,60,76]. Some illusions may be harder to identify than others. For example, patients  
153 with osteoarthritis demonstrate an altered sensorimotor relationship with the affected  
154 limb in addition to the experience of pain [43,87,88]. Evidence from studies of  
155 illusory physical experience can be seen usefully as examples of pain operating as  
156 a liminal phenomenon, unstable and malleable.

157  
158 Embodied pain involves an elision between perception and action, such that pain  
159 without action should be considered unusual, abnormal, or extreme. From this  
160 perspective, chronic pain involves persistent action that attempts to reduce threat over  
161 time. Inescapable pain, where action is inadequate, may be a signal feature of severe

distress eg., total pain, or locked in syndrome) [7]. At risk in inescapable pain is the coherence of all behaviour. There are studies of altered bodily coherence in individuals with CRPS I [67] and observations of dissociation from ownership of a limb [57]. But there are few experimental studies of what can be considered a final defence by departure, in repression, de-realization, or dissociation. In anthropology there are qualitative accounts of specific rites of passage [65], and in social psychology of deviant social practice [8]. In the history of medicine we find rich description of inescapable surgical pain without anaesthesia [14] and in contemporary medicine there are similar accounts, such as in emergency care, or burns care [66]. There is no meta-synthesis of this literature, however, accounts of inescapable pain—of pain denied action—all feature what we call a final defence in a dissociative departure from our body. Although these departures are well studied in clinical neurology, and so have a structure [54] they have not been studied in pain. Evidence from studies of final defence show that only in extreme circumstances does perception cleave from action.

#### 4. Discussion

Pain as embodied and embedded—inferred, liminal, and functioning for defence—has far reaching research and clinical implications (Fig. 1.). Our focus should shift from pain as a passive, sensory experience to pain as a dynamic, motor experience. Pain is always about action [96].

For research, our focus should be on the critical gaps. First, there is a need to explore the changing interactions between experience of the body and associated action (conscious and non-conscious). Studies of proprioception [45], peri-personal space [79], and bodily size [68] have offered the best entry points, but a programme of research into other liminal bodily experiences, such as itch, fatigue, disequilibrium, and respiration are also needed.



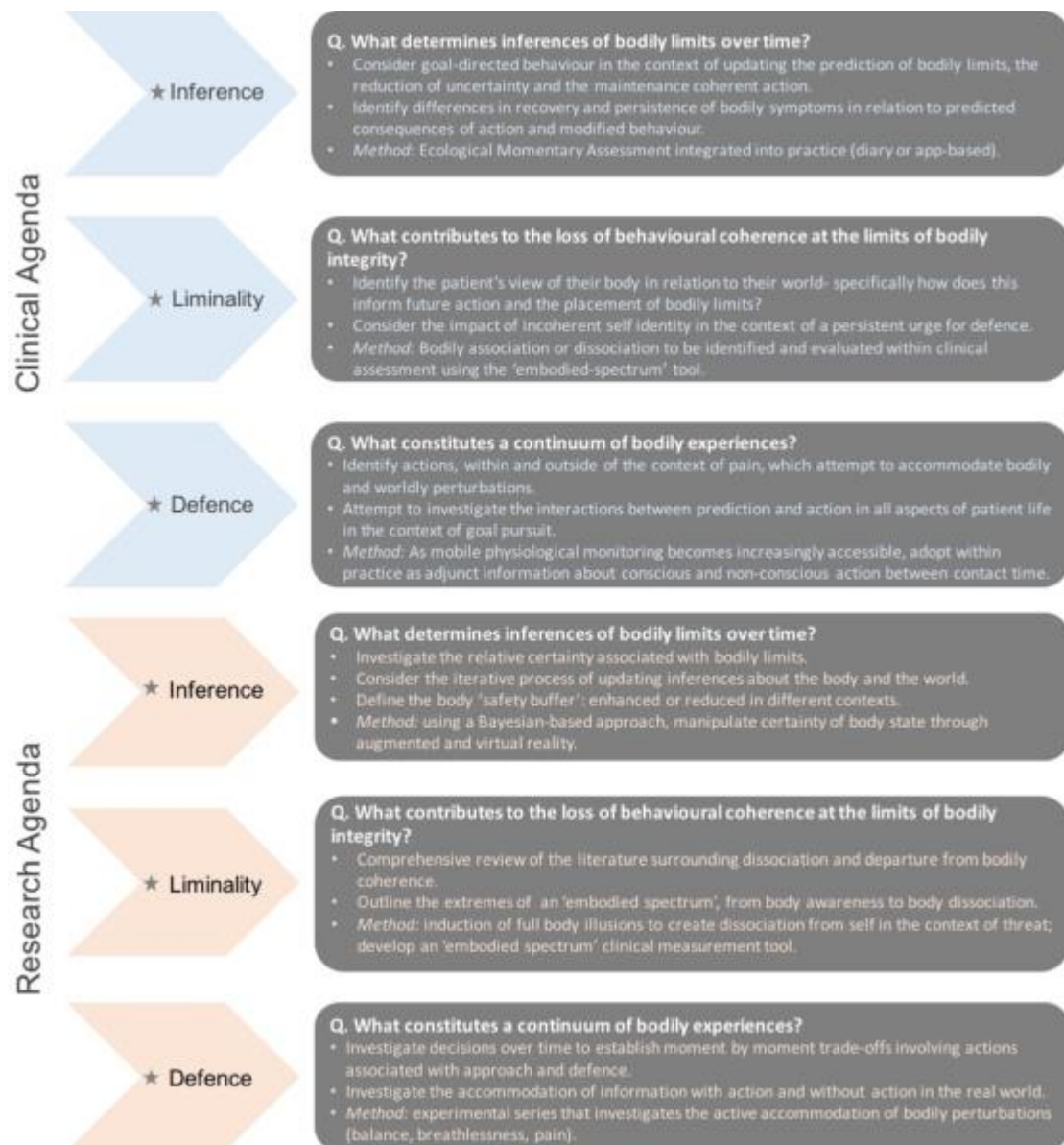


Fig. 1. *Embodied Pain*: proposed research and clinical agendas.

The clinical study of treatments aimed at altering experience should consider actions associated with threat. In part, this approach is concerned with gaining detailed accounts of real-life interactions. In acute pain, there are unexplored opportunities in going beyond simple distraction, making use of the inherent uncertainty associated with our bodily experiences; recognising that we act continually to reduce uncertainty. This line of work is already being pursued with the use of bodily illusions [45,71,76]. In chronic pain, interesting are e-health and m-health innovations that now allow for

moment-by-moment measurement of functional, physiological and experiential parameters in the real world. Clinically, treatments framed within a motivational context of how pain interferes with purposeful goal-orientated behaviour (e.g, completing a work task) may be improved by studying how threat to bodily coherence is managed [16,80]. In particular, accounting for how action and prediction influence individually defined boundaries. We are beginning to think of therapy as the attempt to redefine a stable coherence of one's identity in line with the context of a persistent urge for defence [66].

## 5. Conclusion

We propose that pain is inescapably embodied and embedded; an action that reflects the uncertainty of body and world. '*Embodied pain*' provides a theoretical platform from which novel investigations can aim to understand coherent action in complex, goal-rich environments.

214     References

- 215     [1]     Allport DA. Attention and control: have we been asking the wrong questions?  
216             A critical review of twenty-five years. In: Meyer E, Kornblum S, editors.  
217             Attention and Performance XVI: Synergies in Experimental Psychology,  
218             Artificial Intelligence, and Cognitive Neuroscience. Cambridge, MA: MIT Press,  
219             1993. pp. 182–218.
- 220     [2]     Allport DA. Selection for action: some behavioral and neurophysiological  
221             considerations of attention and action. In: Heuer H, Sanders HF, editors.  
222             Perspectives on Perception and Action. Hillsdale, NJ: Lawrence Erlbaum  
223             Associates, 1987. pp. 395–419.
- 224     [3]     Anchisi D, Zanon M. A Bayesian perspective on sensory and cognitive  
225             integration in pain perception and placebo analgesia. PLoS One 2015;10:1–  
226             20.
- 227     [4]     Ashby WR. An introduction to cybernetics. London: Chapman & Hall Ltd.,  
228             1956.
- 229     [5]     Attridge N, Crombez G, Van Ryckeghem D, Keogh E, Eccleston C. The  
230             experience of cognitive intrusion of pain. Pain 2015;156:1978–90.
- 231     [6]     Aydede M. Is feeling pain the perception of something? J. Philos.  
232             2009;106:531–567.
- 233     [7]     Bauby J-D. The diving bell and the butterfly. London: Fourth Estate, 1997.
- 234     [8]     Baumeister RF. The enigmatic appeal of sexual masochism: why people  
235             desire pain, bondage, and humiliation sex. J. Soc. Clin. Psychol. 1997;16:133–  
236             150.
- 237     [9]     Bechara A, Damasio AR. The somatic marker hypothesis: a neural theory of  
238             economic decision. Games Econ. Behav. 2005;52:336–372.
- 239     [10]    Beierholm UR, Quartz SR, Shams L. Bayesian priors are encoded  
240             independently from likelihoods in human multisensory perception. J. Vis.  
241             2009;9:1–9.

- 242 [11] Benedetti F, Pollo A, Lopiano L, Lanotte M, Vighetti S, Rainero I. Conscious  
243 expectation and unconscious conditioning in analgesic, motor, and hormonal  
244 placebo/nocebo responses. *J. Neurosci.* 2003;23:4315–4323.
- 245 [12] Blackmore SJ. *Beyond the body: an investigation of the out-of-the-body*  
246 *experiences.* London: Heinemann, 1982.
- 247 [13] Blanke O. Out of body experiences and their neural basis. *BMJ*  
248 2004;329:1414–1415.
- 249 [14] Bourke J. *The story of pain: from prayer to painkillers.* Oxford: Oxford  
250 University Press, 2014.
- 251 [15] Bowering KJ, O’Connell NE, Tabor A, Catley MJ, Leake HB, Moseley GL,  
252 Stanton TR. The effects of graded motor imagery and its components on  
253 chronic pain: a systematic review and meta-analysis. *J. Pain* 2013;14:3–13.
- 254 [16] Brandtstadter J, Rothermund K. The life-course dynamics of goal pursuit and  
255 goal adjustment: a two-process framework. *Dev. Rev.* 2002;22:117–150.
- 256 [17] Buchel C, Geuter S, Sprenger C, Eippert F. Placebo analgesia: a predictive  
257 coding perspective. *Neuron* 2014;81:1223–1239.
- 258 [18] Butler DS, Moseley GL. *Explain Pain: revised and updated.* 2nd ed. Adelaide,  
259 SA: Noigroup Publications, 2013.
- 260 [19] Chemero A. An outline of a theory of affordances. *Ecol. Psychol.*  
261 2003;15:181–195.
- 262 [20] Clark. Busting out: predictive brains, embodied minds, and the puzzle of the  
263 evidentiary veil. *Nous* 2016:1–27.
- 264 [21] Clark A. An embodied cognitive science? *Trends Cogn. Sci.* 1999;3:345–351.  
265 doi:10.1016/S1364-6613(99)01361-3.
- 266 [22] Clark A. Embodied Prediction. In: Metzinger T, Windt JM, editors. *Open MIND.*  
267 Frankfurt am Main: MIND Group, 2015. p. 7. doi:10.15502/9783958570115.
- 268 [23] Clark A. Whatever next? Predictive brains, situated agents, and the future of  
269 cognitive science. *Behav. Brain Sci.* 2013;36:181–204.

- 270 [24] Clark A, Chalmers D. The extended mind. *Analysis* 1998;58:7–19.
- 271 [25] Craig AD. A new view of pain as a homeostatic emotion. *Trends Neurosci.*  
272 2003;26:303–307.
- 273 [26] Crombez G, Eccleston C, Baeyens F, Eelen P. Disruptive nature of pain: an  
274 experimental investigation. *Behav. Res. Ther.* 1996;34:911–918.
- 275 [27] Crombez G, Eccleston C, Van Damme S, Vlaeyen JWS, Karoly P. Fear-  
276 avoidance model of chronic pain: the next generation. *Clin. J. Pain*  
277 2012;28:475–83.
- 278 [28] Damasio A, Carvalho GB. The nature of feelings: evolutionary and  
279 neurobiological origins. *Nat. Rev. Neurosci.* 2013;14:143–52.
- 280 [29] Van Damme S, Legrain V, Vogt J, Crombez G. Keeping pain in mind: a  
281 motivational account of attention to pain. *Neurosci. Biobehav. Rev.*  
282 2010;34:204–213.
- 283 [30] Davis KD. Neuroimaging of pain: what does it tell us? *Curr. Opin. Support.*  
284 *Palliat. Care* 2011;5:116–121.
- 285 [31] Dayan P, Kakade S, Montague PR. Learning and selective attention. *Nat.*  
286 *Neurosci.* 2000;3:1218–1223.
- 287 [32] Dennett DC. Quining qualia. In: Marcel A, Bisiach E, editors. *Consciousness in*  
288 *Modern Science.* Oxford: Oxford University Press, 1988.
- 289 [33] Eccleston C, Crombez G. Worry and chronic pain: a misdirected problem  
290 solving model. *Pain*, 132; 233-236.
- 291 [34] Eccleston C, Crombez G. Pain demands attention: a cognitive-affective model  
292 of the interruptive function of pain. *Psychol Bull* 1999;125:356–366.
- 293 [35] Eccleston C, Crombez G, Aldrich S, Stannard C. Attention and somatic  
294 awareness in chronic pain. *Pain* 1997;72:209–215.
- 295 [36] Engel GL. The need for a new medical model: A challenge for biomedicine.  
296 *Science.* 1977;196:129–136.
- 297 [37] Firestone C, Scholl BJ. Cognition does not affect perception: Evaluating the

298 evidence for “top-down” effects. *Behav. Brain Sci.* 2015;1–72. Available:  
 299 doi.org/10.1017/s0140525x15000965.

300 [38] Freud S. The Uncanny. In: Strachey J, editor. The standard edition of the  
 301 complete psychological works of Sigmund Freud (Vol 17). London: The  
 302 Hogarth Press, 1919. pp. 218–256.

303 [39] Friston K. The free-energy principle: a unified brain theory? *Nat. Rev.*  
 304 *Neurosci.* 2010;11:127–138.

305 [40] Gallagher S, Bower M. Making enactivism even more embodied. *Avant Trends*  
 306 *Interdiscip. Stud.* 2014;2:232–247.

307 [41] Gibson JJ. The Theory of Affordances. In: Shaw R, Bransford J, editors.  
 308 *Perceiving, Acting, and Knowing. Towards an Ecological Psychology.*  
 309 Hoboken, NJ: John Wiley & Sons Inc., 1977. pp. 127–142.

310 [42] Gifford L. Pain, the Tissues and the Nervous System: A conceptual model.  
 311 *Physiotherapy* 1998;84:27–36.

312 [43] Gilpin HR, Moseley GL, Stanton TR, Newport R. Evidence for distorted mental  
 313 representation of the hand in osteoarthritis. *Rheumatology* 2014;54:678–682.

314 [44] Gregory RL. Perceptions as hypotheses. *Philos. Trans. R. Soc. B Biol. Sci.*  
 315 1980;290:181–197.

316 [45] Harvie DS, Broecker M, Smith RT, Meulders A, Madden VJ, Moseley GL.  
 317 Bogus visual feedback alters onset of movement-evoked pain in people with  
 318 neck pain. *Psychol. Sci.* 2015;26:385–92.

319 [46] Haugeland J. Mind embodied and embedded. In: Haugeland J, editor. *Having*  
 320 *Thought: Essays in the Metaphysics of Mind.* Cambridge, MA: Harvard  
 321 University Press, 1998.

322 [47] Heidegger M. *Being and Time.* trans. J. Macquarrie and E Robinson, editor  
 323 Tübingen: Max Niemeyer Verlag, 1962.

324 [48] Helmholtz H von. *Handbuch der physiologischen optik, vol 3. (Trans.).*  
 325 Southall JPC, editor New York, NY: Dover Publications, 1962.

- 326 [49] Helmholtz H von. Treatise on physiological optics, vol. II. 1924.
- 327 [50] Hohwy J. Attention and conscious perception in the hypothesis testing brain.
- 328 Front. Psychol. 2012;2:96.
- 329 [51] Hohwy J. The predictive mind. Oxford: Oxford University Press, 2013.
- 330 [52] Humphrey N. The placebo effect. In: Gregory R, editor. Oxford companion to
- 331 the mind. Oxford: Oxford University Press, 2005.
- 332 [53] Husserl E. Ideas: a general introduction to pure phenomenology. Trans. W. R
- 333 Boyce Gibson, editor New York: Collier Books, 1931.
- 334 [54] Kihlstrom JF. Dissociative Disorders. Annu. Rev. Clin. Psychol. 2005;1:227–
- 335 253.
- 336 [55] Körding KP, Wolpert DM. Bayesian integration in sensorimotor learning.
- 337 Nature 2004;427:244–247.
- 338 [56] Legrain V, Damme S Van, Eccleston C, Davis KD, Seminowicz DA, Crombez
- 339 G. A neurocognitive model of attention to pain: behavioral and neuroimaging
- 340 evidence. Pain 2009;144:230–232.
- 341 [57] Lewis JS, Schweinhardt P. Perceptions of the painful body: the relationship
- 342 between body perception disturbance, pain and tactile discrimination in
- 343 complex regional pain syndrome. Eur. J. Pain 2012;16:1320–1330.
- 344 [58] Lopez C, Halje P, Blanke O. Body ownership and embodiment: vestibular and
- 345 multisensory mechanisms. Neurophysiol. Clin. 2008;38:149–161.
- 346 [59] Malloy KM, Milling LS. The effectiveness of virtual reality distraction for pain
- 347 reduction: a systematic review. Clin. Psychol. Rev. 2010;30:1011–1018.
- 348 [60] Mancini F, Longo MR, Kammers MPM, Haggard P. Visual distortion of body
- 349 size modulates pain perception. Psychol. Sci. 2011;22:325–330.
- 350 [61] Mano H, Seymour B. Pain: a distributed brain information network? PLoS Biol.
- 351 2015;13:e1002037.
- 352 [62] Merleau-Ponty M. Phenomenology of Perception (Trans.). Smith C, editor
- 353 London: Routledge & Kegan Paul, 1962.

- 354 [63] Moayedi M, Davis KD. Theories of pain: from Specificity to Gate Control. J.  
355 Neurophysiol. 2013;109:5–12.
- 356 [64] Moore A, Derry S, Eccleston C, Kalso E. Expect analgesic failure; pursue  
357 analgesic success. Br. Med. J. 2013;346:f2690–f2690.
- 358 [65] Morinis A. The ritual experience: pain and the transformation of consciousness  
359 in ordeals of initiation. Ethos 1985;13:150–174.
- 360 [66] Morse JM, Mitcham C. The experience of agonizing pain and signals of  
361 disembodiment. J. Psychosom. Res. 1998;44:667–680.
- 362 [67] Moseley GL. Distorted body image in complex regional pain syndrome.  
363 Neurology 2005;65:773–778.
- 364 [68] Moseley GL, Gallace A, Spence C. Bodily illusions in health and disease:  
365 physiological and clinical perspectives and the concept of a cortical “body  
366 matrix.” Neurosci. Biobehav. Rev. 2012;36:34–46.
- 367 [69] Moseley GL, Parsons TJ, Spence C. Visual distortion of a limb modulates the  
368 pain and swelling evoked by movement. Curr. Biol. 2008;18:R1047-8.
- 369 [70] Moseley GL, Vlaeyen JWS. Beyond nociception: the imprecision hypothesis of  
370 chronic pain. Pain 2015;156:35–38.
- 371 [71] Murray CD, Pettifer S, Howard T, Patchick EL, Caillette F, Kulkarni J, Bamford  
372 C. The treatment of phantom limb pain using immersive virtual reality: three  
373 case studies. Disabil. Rehabil. 2007;29:1465–1469.
- 374 [72] Nikolajsen L, Jensen ST. Phantom limb pain. Br. J. Anaesth. 2001;87:107–  
375 116.
- 376 [73] Noe A. Action in perception. Cambridge, MA: MIT Press, 2004 p.
- 377 [74] O'Regan JK, Dagenaar J. Consciousness without inner models: a  
378 sensorimotor account of what is going on in our heads. Proc. AISB 2014.
- 379 [75] Prescott TJ, Bryson JJ, Seth AK. Introduction. Modelling natural action  
380 selection. Philos. Trans. R. Soc. B Biol. Sci. 2007;362:1521–1529.
- 381 [76] Preston C, Newport R. Analgesic effects of multisensory illusions in



382           osteoarthritis. *Rheumatology* 2011;50:2314–2315.

383   [77]   Proffitt DR. An embodied approach to perception: by what units are visual  
384           perceptions scaled? *Perspect. Psychol. Sci.* 2013;8:474–483.

385   [78]   Rao RPN, Ballard DH. Predictive coding in the visual cortex: a functional  
386           interpretation of some extra-classical receptive-field effects. *Nat. Neurosci.*  
387           1999;2:79–87.

388   [79]   Sambo CF, Iannetti GD. Better safe than sorry? The safety margin  
389           surrounding the body is increased by anxiety. *J. Neurosci.* 2013;33:14225–30.

390   [80]   Schmitz U, Saile H, Nilges P. Coping with chronic pain: flexible goal  
391           adjustment as an interactive buffer against pain-related distress. *Pain*  
392           1996;67:41–51.

393   [81]   Seth AK. The Cybernetic Bayesian Brain. In: Metzinger T, Windt JM, editors.  
394           Open MIND. Frankfurt am Main: MIND Group, 2015;35.  
395           doi:10.15502/9783958570108.

396   [82]   Seth AK. The ecology of action selection: insights from artificial life. *Philos.*  
397           *Trans. R. Soc. Lond. B. Biol. Sci.* 2007;362:1545–1558.

398   [83]   Seth AK. Why fish pain cannot and should not be ruled out. *Anim. Sentience*  
399           2016;3:1–5.

400   [84]   Seth AK, Suzuki K, Critchley HD. An interoceptive predictive coding model of  
401           conscious presence. *Front. Psychol.* 2012;3:1–16.

402   [85]   Seymour B, Dolan RJ. Emotion, Motivation, and Pain. In: McMahon S,  
403           Koltzenburg M, Tracey I, Turk DC, editors. *Wall and Melzack's Textbook of*  
404           *Pain*. Philadelphia, PA: Saunders, Elsevier Ltd, 2013. pp. 248–255.

405   [86]   Shapiro LA. *The mind incarnate*. Cambridge, MA: MIT Press, 2004.

406   [87]   Stanton TR, Lin CWC, Bray H, Smeets RJEM, Taylor D, Law RYW, Moseley  
407           GL. Tactile acuity is disrupted in osteoarthritis but is unrelated to disruptions in  
408           motor imagery performance. *Rheumatology* 2013;52:1509–1519.

409   [88]   Stanton TR, Lin CWC, Smeets RJEM, Taylor D, Law R, Lorimer Moseley G.

410           Spatially defined disruption of motor imagery performance in people with  
411           osteoarthritis. *Rheumatology* 2012;51:1455–1464.

412   [89]   Sullivan MD. Pain in language. From sentience to Sapience. *J. Pain* 1995;4:3–  
413           14.

414   [90]   Sullivan MJ, Thibault P, Savard A, Catchlove R, Kozey J, Stanish WD. The  
415           influence of communication goals and physical demands on different  
416           dimensions of pain behavior. *Pain* 2006;125:270–277.

417   [91]   Tabor A, Catley MJ, Gandevia SC, Thacker M a., Spence C, Moseley GL. The  
418           close proximity of threat: altered distance perception in the anticipation of pain.  
419           *Front. Psychol.* 2015;6:1–6.

420   [92]   Tang NKY, Salkovskis PM, Hodges A, Wright KJ, Hanna M, Hester J. Effects  
421           of mood on pain responses and pain tolerance: an experimental study in  
422           chronic back pain patients. *Pain* 2008;138:392–401.

423   [93]   Titchener EB. Structural and functional psychology. *Philos. Rev.* 1899;8:290–  
424           299.

425   [94]   Trimmer PC, Marshall JAR, Fromhage L, McNamara JM, Houston AI.  
426           Understanding the placebo effect from an evolutionary perspective. *Evol.*  
427           *Hum. Behav.* 2013;34:8–15.

428   [95]   Varela F, Rosch E, Thompson E. The embodied mind: cognitive science and  
429           human experience. Cambridge, MA: MIT Press, 1991.

430   [96]   Wall PD. On the relation of injury to pain. The John J. Bonica Lecture. *Pain*  
431           1979;6:253–264.

432   [97]   Wall PD. Pain: the science of suffering. New York, NY: Columbia University  
433           Press, 2000.

434   [98]   Wiech K, Ploner M, Tracey I. Neurocognitive aspects of pain perception.  
435           *Trends Cogn. Sci.* 2008;12:306–313.

436   [99]   Wiech K, Tracey I. Pain, decisions, and actions: a motivational perspective.  
437           *Front. Neurosci.* 2013;7:1–12.

438 [100] Wiech K, Vandekerckhove J, Zaman J, Tuerlinckx F, Vlaeyen JWS, Tracey I.  
 439 Influence of prior information on pain involves biased perceptual decision-  
 440 making. *Curr. Biol.* 2014;R679–R681.  
 441 [101] Williams AC de C. What can evolutionary theory tell us about chronic pain?  
 442 *Pain* 2015;157:1.  
 443 [102] Witt JK, Linkenauger SA, Bakdash JZ, Augustyn JS, Cook A, Proffitt DR. The  
 444 long road of pain: chronic pain increases perceived distance. *Exp. Brain Res.*  
 445 2009;192:145–148.  
 446 [103] Yuille AL, Bulthoff HH, Kersten D, Mamassian P. Perception as Bayesian  
 447 Inference. *Annu. Rev. Psychol.* 1996;55:271–304.  
 448